



METALLURGICAL EXAMINATION OF A DAMAGED V-22 HYDRAULIC LINE

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13. ABSTRACT (Maximum 200 words) A preliminary metallurgical investigation of the damaged, Ti-3A1-2.5V, V-22 System 1 Pump Suction Tube of the V-22 Osprey aircraft, identified as 901-081-904-101, has been completed. The 1.0 inch (2.54 cm) diameter tube sustained localized damage where it was secured by a rubber clamp to the transmission. That portion of the tube was excised, sectioned, and examined using metallography and a Scanning Electron Microscope (SEM). Qualitative chemical analysis utilizing Energy Dispersive Spectroscopy (EDS) was performed on the clamp and alloy. Results obtained indicate that the damage was due to fretting. No conclusive evidence was found for corrosion, such as the presence of by-products or an alteration in microstructure.				
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Introduction

A damaged section of a V-22 (Osprey Aircraft #3) hydraulic pump suction line (901-081-904-101) was received for metallurgical analysis. The 1.0 inch (2.54 cm) outer diameter by 0.036 inch (0.09 cm) wall thickness tube of Ti-3Al-2.5V per AMS 4945, was approximately 3 feet (0.91 m) long and bent into a "J" shape. The front and aft sections of the tube had been fastened with hydraulic beam seal fittings. A 0.5 inch (1.27 cm) wide rubber clamp (acrylonitrile butadiene copolymer) within a steel bracket, along the tube's mid-section, was used to secure it to the transmission of the V-22.

3Al-2.5V Titanium Alloy

One of the most important uses for 3Al-2.5V Titanium Alloy to date has been for aircraft hydraulic lines that require strength, an oxidation resistance up to 600°F (316°C), fabricability, and an optimum fatigue life. To satisfy these requirements, the titanium alloy has been formed into a seamless, cold worked, stress-relieved, and texture controlled tubing.¹ Other forms available for this alloy include sheet, strip, and foil. Additional advantages of using titanium and its alloys in the aircraft industry are: weight savings (less dense than steel), volume constraints (aircraft structure), and operating temperature (higher than aluminum).² The alloy is currently specified for advanced fighter designs (i.e. F-14, F-15, C5A and B-1) as well as the supersonic transport; increased usage can be expected as actual flight experience develops. This alloy resists general attack, pitting, intergranular, and crevice corrosion.³ It possesses excellent cavitation and erosion resistance. It has an equal or better stress-corrosion cracking characteristics than other titanium alloys due to the lower aluminum content.

Traditional methods of fabrication for the titanium alloy tube include the cold pilger mill, a drawbench, or a combination of both modes of production. An example of tube production involves the following: 1) The hollows are fabricated from the ingot or billet. 2) They are then reduced through several stages. 3) The tube diameter is reduced through dies, while the inside diameter is supported by a rod of certain diameter. The ratio between the reduction of the diameter and the wall thickness controls the tubing texture, causing it to be circumferential, radial, or in between. 4) Each reduction is followed by annealing or stress-relieving cycles.⁴ For tubing fabrication, stress-relieving is performed at a minimum temperature of 600°F (316°C). A very high strength-to-weight ratio is achieved while maintaining good fabricability (weldability). Mechanical properties for this temper in normal hydraulic lines sizes are as follows:

- Minimum Ultimate Tensile Strength of 125000 psi (8.6 MPa)
- Minimum (0.2% Offset) Yield Strength of 105000 psi (7.2 MPa)
- Elongation in 2" (5.0 cm) of 8% minimum.

In the stress-relieved condition, 3Al-2.5V alloy is capable of bending around a 3D centerline bend radius when carefully controlled equipment and bending techniques are employed; satisfactory flattening is limited to 12 x wall thickness. For most sizes, flaring per MS33584 can be performed.⁵

Rubber (Acrylonitrile-Butadiene Copolymer) Clamp

The rubber clamp used to secure the hydraulic line to the transmission of the V-22 was of a standard specification, MIL-C-85052/1-16, which is utilized in most military aircraft. It is a cushioned p-clamp of a yellow acrylonitrile butadiene copolymer blended with polyvinyl chloride. A traditional blend is 70/30 nitrile to PVC. This elastomer has been selected for hydraulic line fixation because of its chemical resistance to oil and ozone and its good physical characteristics or properties. The typical (installation) environment for which this clamp is subjected to is harsh; the clamp encounters high vibration due to numerous rotating components, a high tubing contact

temperatures (up to 240°F/160°C), and a dirty backwash of the propeller accompanied by a cooling airflow.

Experimental

Macroscopic Examination

The damaged surface of the V-22 hydraulic line was photographed (Polaroid Film 52) at 1X and 5X magnifications with a Polaroid Land Camera.

Metallography

The damaged area of the hydraulic line was then excised using the Radiac band saw and mounted in Diallyl Phthalate. Grinding was achieved on the following successive papers: 240, 300, and 500 grit. Polishing was performed with 0.3 (alpha) and 0.05 (gamma) micron alumina. Samples were then etched in Kroll's reagent (3:1) for observation on the metallograph. A Bausch & Lomb Metallograph was used to examine the microstructure at magnifications ranging from 50X to 400X.

Scanning Electron Microscopy and Electron Dispersive Spectroscopy

An Amray 1000B scanning electron microscope operating at 12 keV was used to examine the damaged section (surface and cross-section) of the hydraulic line and the connecting rubber clamp. An ultra-thin window detector was used in conjunction with a Kevex analyzer in order to perform elemental analyses. A nascent rubber clamp was also obtained and analyzed as a control.

Microhardness

Hardness measurements from two mounted cross-sections of the damaged area were obtained with a Tukon Microhardness Tester. The testing conditions involved a 200 gram load and a 40X objective lens with a calibration factor of 0.2142.

Results

Macroscopic Observations

A macroscopic image of the damaged portion of the hydraulic line is presented in **Figure 1**. The damage is localized to the contact area of the rubber clamp: approximately 0.5 inches wide that extends around the exterior circumference of the tube. This area could be described as a rough discolored surface containing small shallow pits (some with darkened areas) and scratches. In addition, the contact area of the rubber clamp was found to contain a black gritty material.

Microscopic Observations

Figures 2 and 3 are SEM micrographs of the damaged surface and the corresponding cross-section of the pump suction tube (as-received). Pits and gouges were detected on the surface; no evidence of cracking and intergranular attack was found. However, there was some directionality observed with the orientation of some pits. These particular pits were aligned as if created by some mechanical means. The micrographs also reveal a fine grained, oriented alpha-beta microstructure, in which the alpha is observed as the lighter phase dispersed in the darker beta matrix.

A profile of a representative cross-section of the damaged tube is portrayed in **Figure 4**. This was constructed from a compilation of linear measurements of the damaged tube's cross-section taken from optical micrographs (of which an example is also included in **Figure 4**). A maximum pit depth was measured to be approximately 30 mils (0.07 cm). The average thickness of the V-22 hydraulic line was determined to be 1750 mils (4.45 cm) with a standard deviation of 50 mils (0.13 cm).

SEM/EDS

The surface of the damaged tube was observed to be pitted with an indication of abrasion, **Figure 2**. There was a bimodal distribution of pit sizes. The larger pits were rounded with scratches running through them. The smaller pits were more clearly defined with sharp edges. Generally, the surface of the tube was free of oxides and other corrosion products (e.g. titanium hydrates). Upon close examination of the pitted areas, a second phase of particles was found. EDS results of these second phase products are displayed in **Figures 5 and 6**, indicating a presence of Al and O. However, only constituent elements of Ti-3Al-2.5V were detected in the cross-sectional area of the damaged tube, as shown in the spectrum of **Figure 7**.

With regard to the corresponding contact area of the rubber clamp, large peaks of Si and O were identified by EDS (**Figure 8**). Furthermore, the black gritty area of the clamp, when compared to the nascent rubber, was discovered to contain large peaks of C, Na, O, and S with an additional presence of Ca and K (**Figure 9**). This result is similar to the EDS spectrum of the darkened pit areas of the tube (**Figure 10**).

Microhardness

The results obtained from the Tukon Microhardness Tester on the damaged and undamaged cross-sectional areas of the tube are presented in Table I below. No statistically significant difference in the hardness of the damaged and undamaged areas can be reported. Data was within the limits of the test performance.

Table I: Tukon Microhardness Testing Results of the Damaged V-22 Hydraulic Line

V-22 Hydraulic Line Cross-Sectional Area:	Knoop Hardness Number:	
	Average Reading:	Standard Deviation:
Undamaged	13.6	1.8
Damaged	13.9	3.2

Discussion

Initial observations of the damaged surface of the V-22 Hydraulic Line suggested that its cause was a consequence of either abrasion, corrosion, or a combination of both. Identification of the causative process required a metallurgical evaluation of the damaged area's surface and cross-section and also of the contacting rubber clamp.

Optical and SEM Microscopy

The directionality of the pits seen on the surface of the damaged tube, as shown in **Figure 2**, tends to imply some type of abrasion due to mechanical means. In addition, after metallographical preparation of the transverse section of the damaged area, no alteration in microstructure was detected; despite the existence of minor surface damage - depressions, as seen in **Figure 4**. Therefore, no microstructural indication of corrosion was present; but there was evidence of good texture control of the tubing (**Figure 3**). In general, the surface topography of

the damaged hydraulic line tended to resemble those that are caused by classic cases of fretting, more particular to its early onset.

Quantitative Analyses

To determine the magnitude of the damage present on the V-22 Hydraulic line, linear measurements were made of the corresponding cross-section along with microhardness testing. However, no conclusions could be deduced since the results from the Tukon Microhardness testing displayed no statistical significance (**Table I**). Moreover, the magnitude of the damage present on the tube was not very extensive, as measured from its cross-section (**Figure 4**). Generally, one would expect to see a difference in the mechanical properties of the titanium alloy tube with the existence of a corrosion attack or severe deformation.

EDS

Elemental analyses (EDS) had shown a large quantity of foreign elements present in both the damaged area (surface) of the tube and its connecting rubber clamp, but not in its corresponding cross-section, **Figures 6-10**. Yet, there was no evidence of any corrosion by-products. However, identifying the foreign particulates as largely sand (SiO_2) and alumina (Al_2O_3), as seen from the resulting spectra of **Figures 6 and 8** respectively, had suggested that it was most likely the hostile environment that this piece of suction tube was subjected to that led to the contamination of the contact areas of its surface and of the rubber clamp; thereby created the damage observed. This was also verified from the two similar spectra obtained of the darkened areas on the pitted surface and on the rubber clamp, **Figures 9 and 10**.

The evidence suggests that the damage done to the V-22 hydraulic line was from the cyclical and vibratory motion of very small foreign particulates, obtained from the surroundings, that became embedded in and between the surfaces of the tube and of the contacting rubber clamp. Elimination of these contaminants would smoothen the contact surfaces and prevent any premature damage of this pump suction tube from occurring and/or recurring.

Conclusions

1. The damage observed on the V-22 Hydraulic Line is attributed to fretting.
2. The microstructure of the damaged tube showed no evidence of corrosion and verified good texture controlled processing of the tubing.

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Acknowledgement

The authors would like to thank Mr. Joseph Bebey of the Naval Air Warfare Center Aircraft Division Warminster, code 435100R, for his technical assistance in this evaluation.

Figure 1: A Polaroid photograph of the excised damaged section of the V-22 Hydraulic Line.
Magnification = 1X.

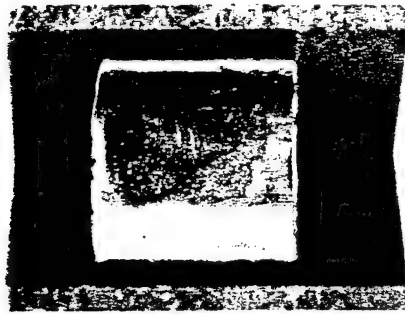


Figure 2: SEM micrographs of the damaged surface of the V-22 Hydraulic Line (as-received).

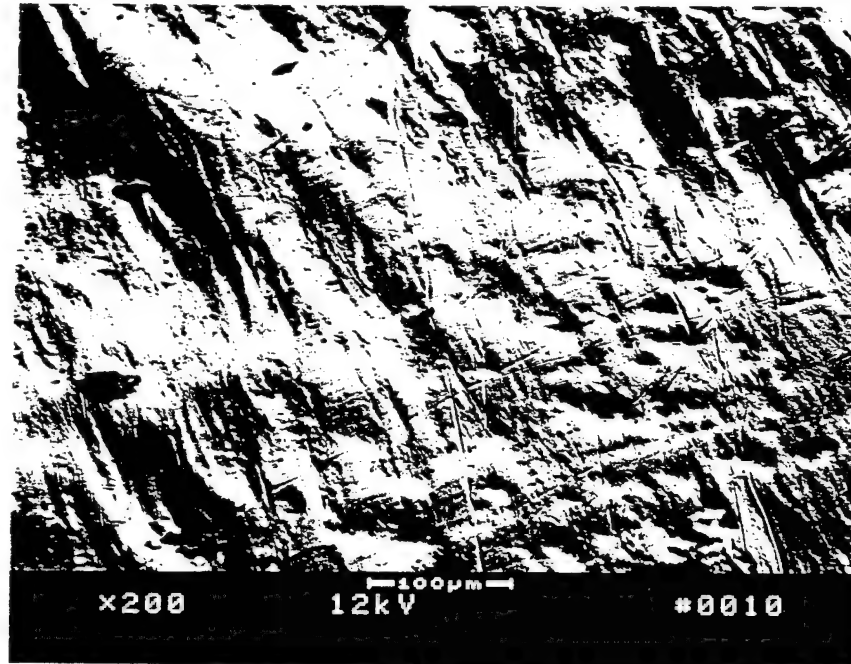


Figure 3: SEM micrographs of the damaged cross-section of the V-22 Hydraulic Line.
Samples were polished and etched in Kroel's reagent (3:1).

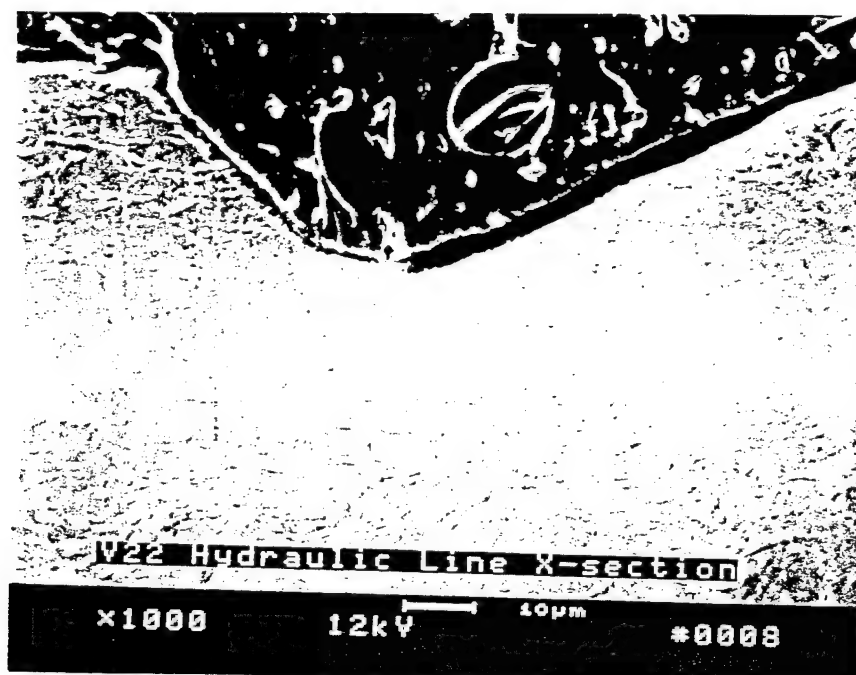
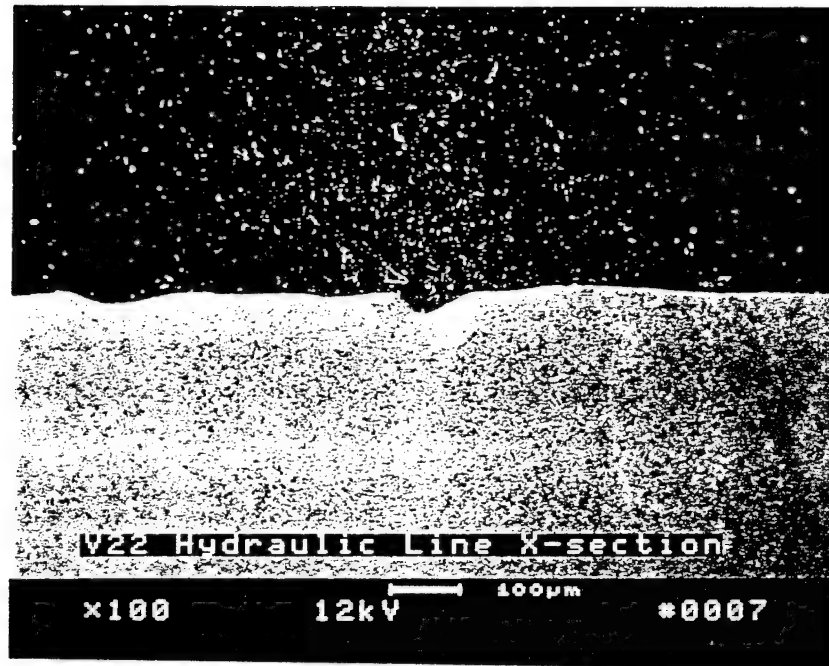
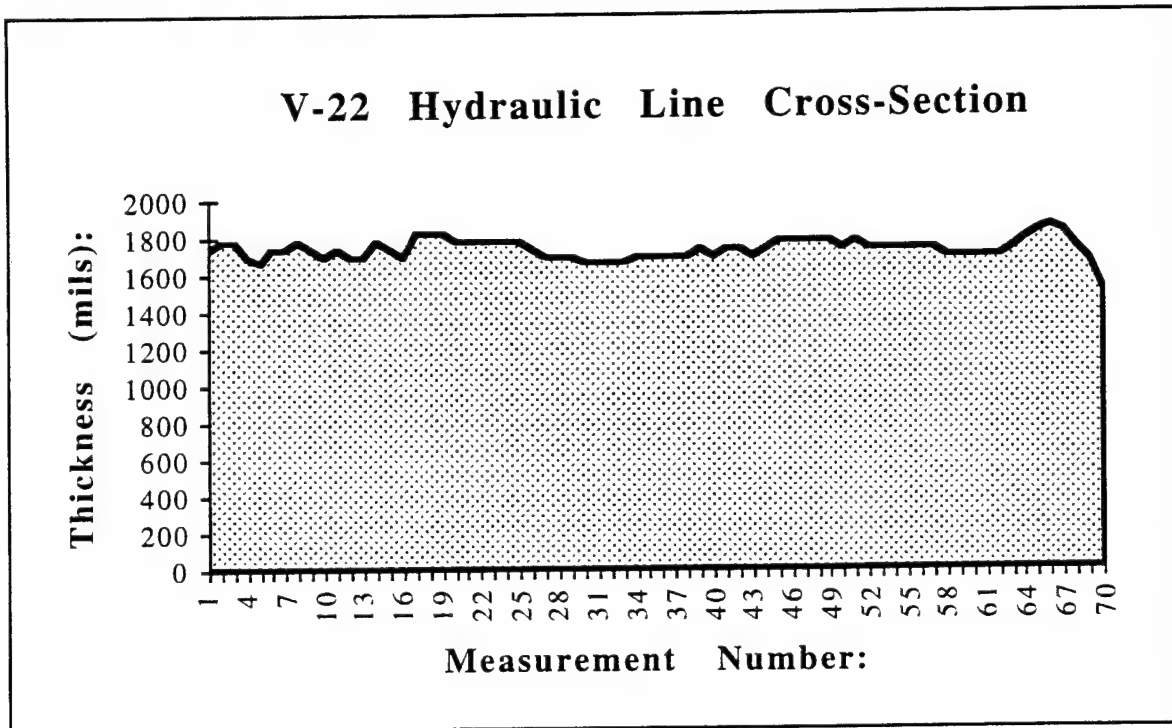
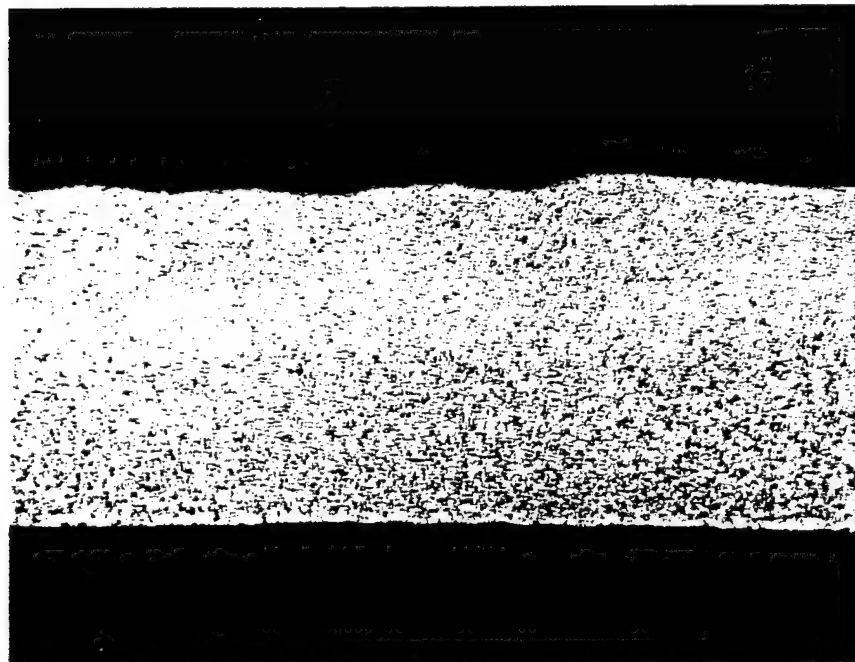


Figure 4: A compiled cross-section of the damaged V-22 Hydraulic Line obtained with linear measurements taken from optical micrographs of the entire cross-section.
(An example of a photographed cross-sectional area is shown below.)



1 mil = 0.001 inch = 0.00254 cm.



201

2

0.00254

V-22, HYD. LINE

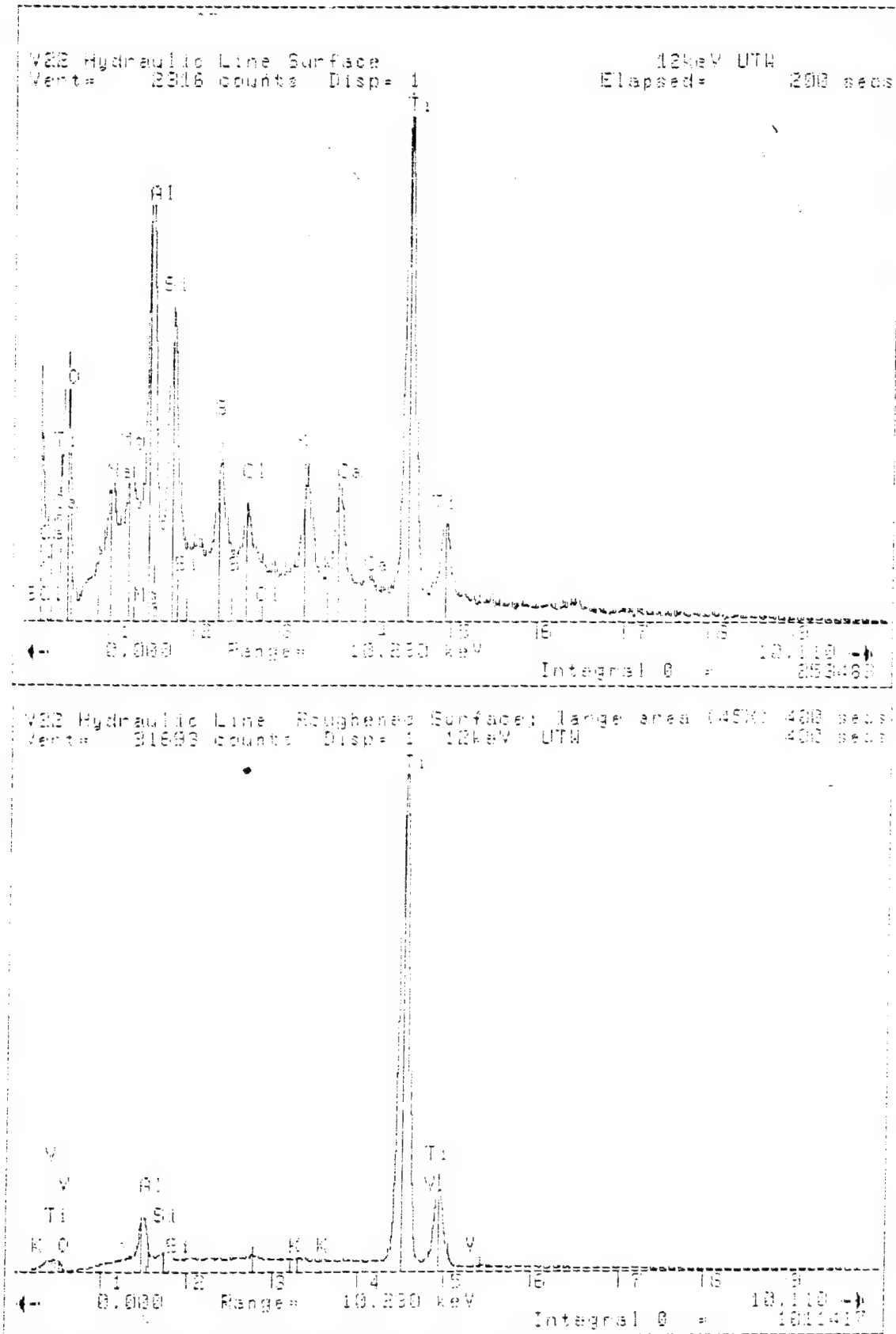
Figure 5: Elemental analyses (EDS) of the damaged surface of the V-22 Hydraulic Line.

Figure 6: Elemental analysis (EDS) of the foreign particulates discovered of the surface of the damaged V-22 Hydraulic Line.

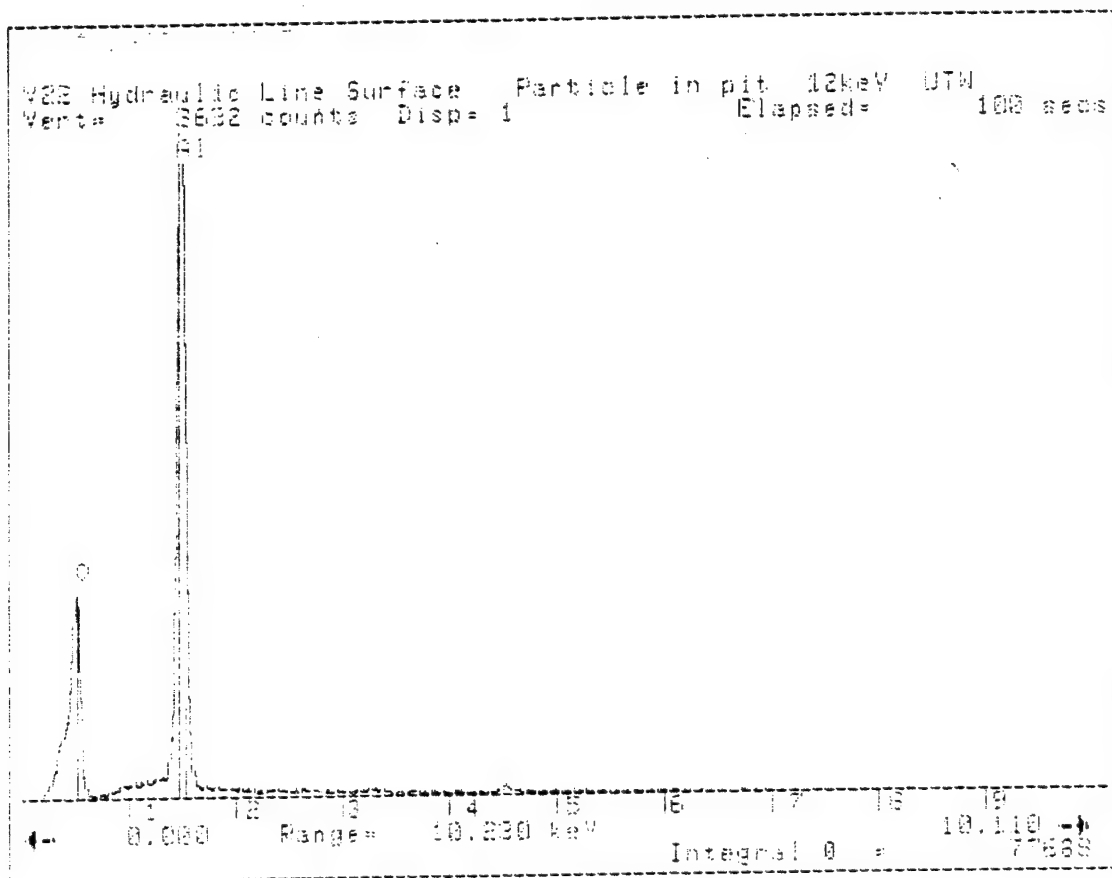


Figure 7: Elemental analysis (EDS), along with its corresponding SEM micrograph, of the damaged V-22 Hydraulic Line's cross-section. Sample had been polished and etched in Kroll's reagent (3:1).

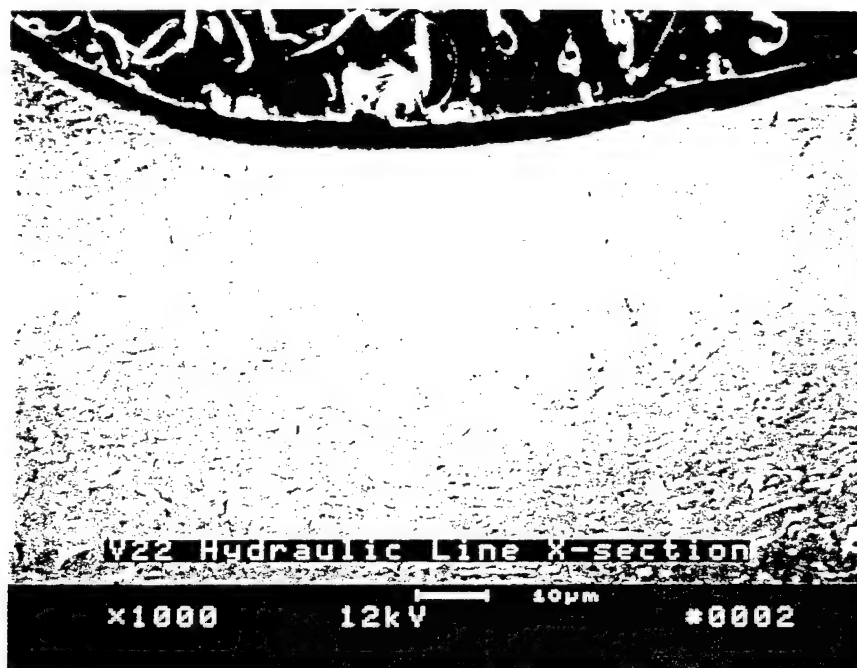
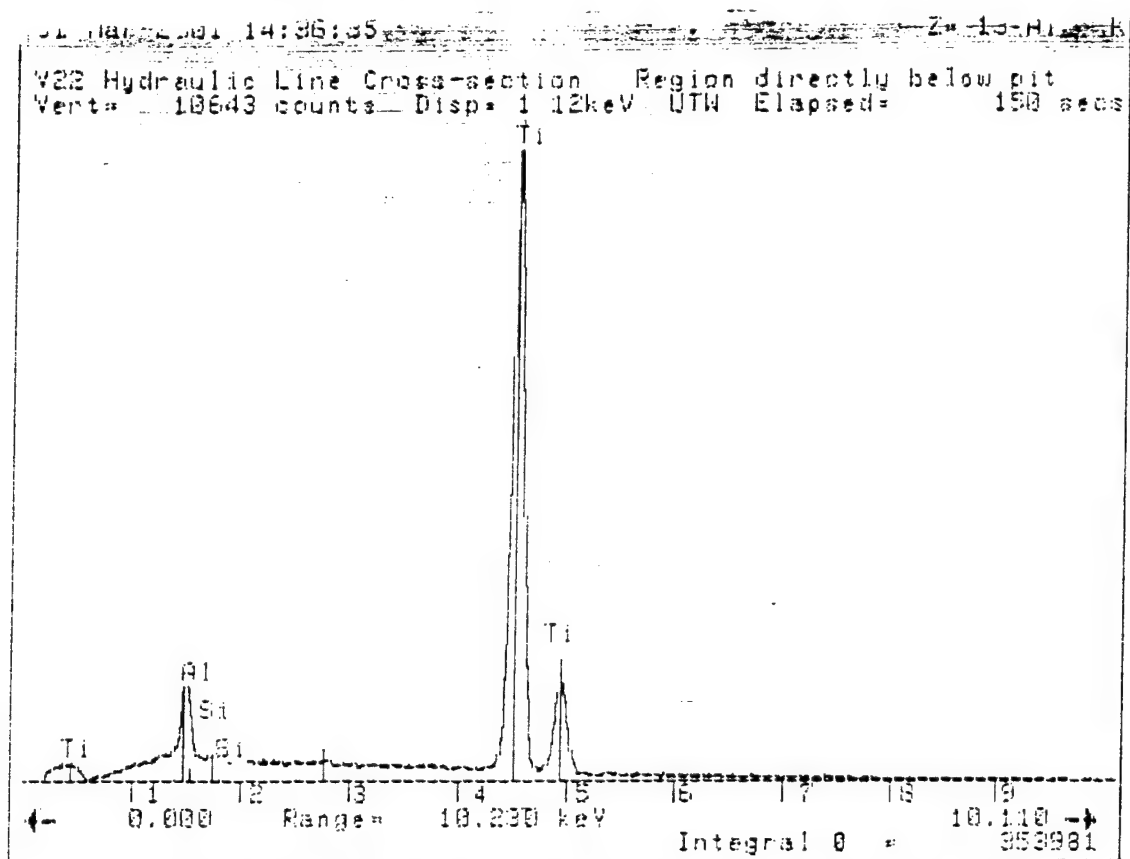


Figure 8: Elemental analysis (EDS) of the rubber clamp's surface that was in contact with the damaged V-22 Hydraulic Line.

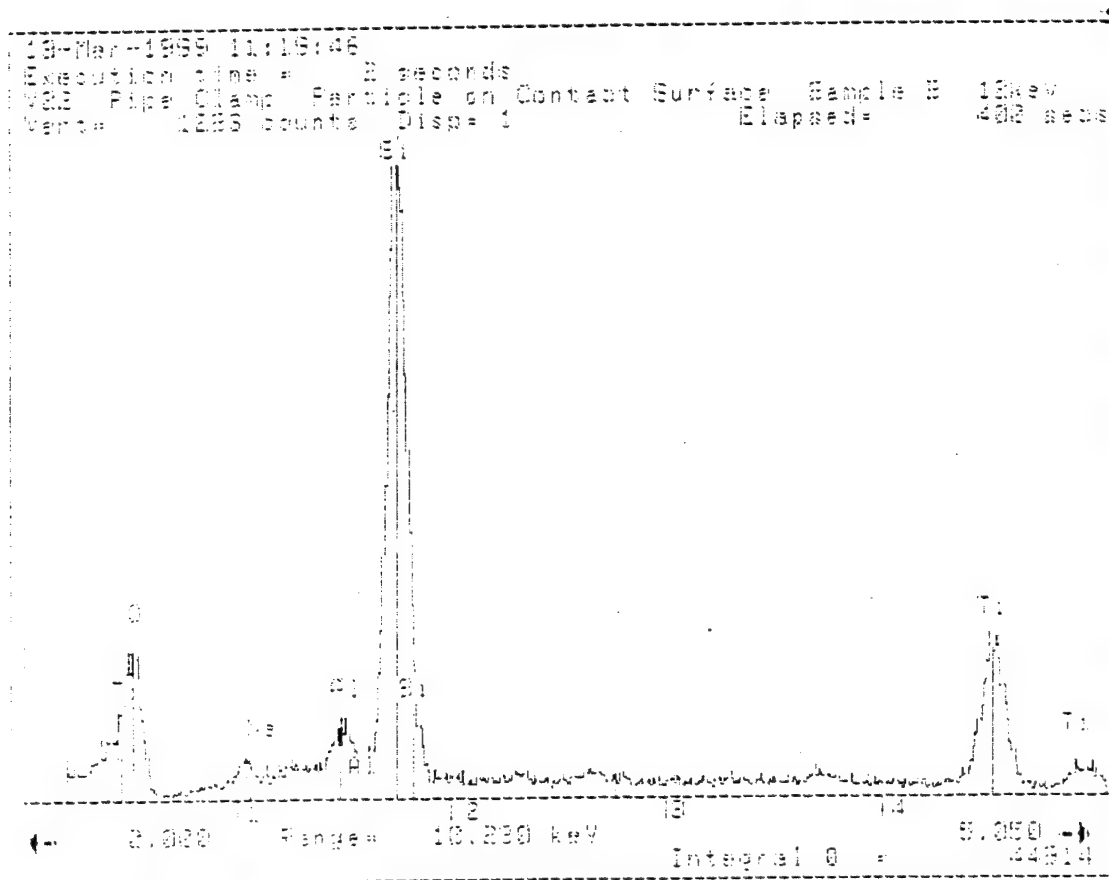


Figure 9: Elemental analyses (EDS) of the damaged V-22 Hydraulic Line's contacting rubber clamp and of a nascent rubber clamp (of same mil-spec.).

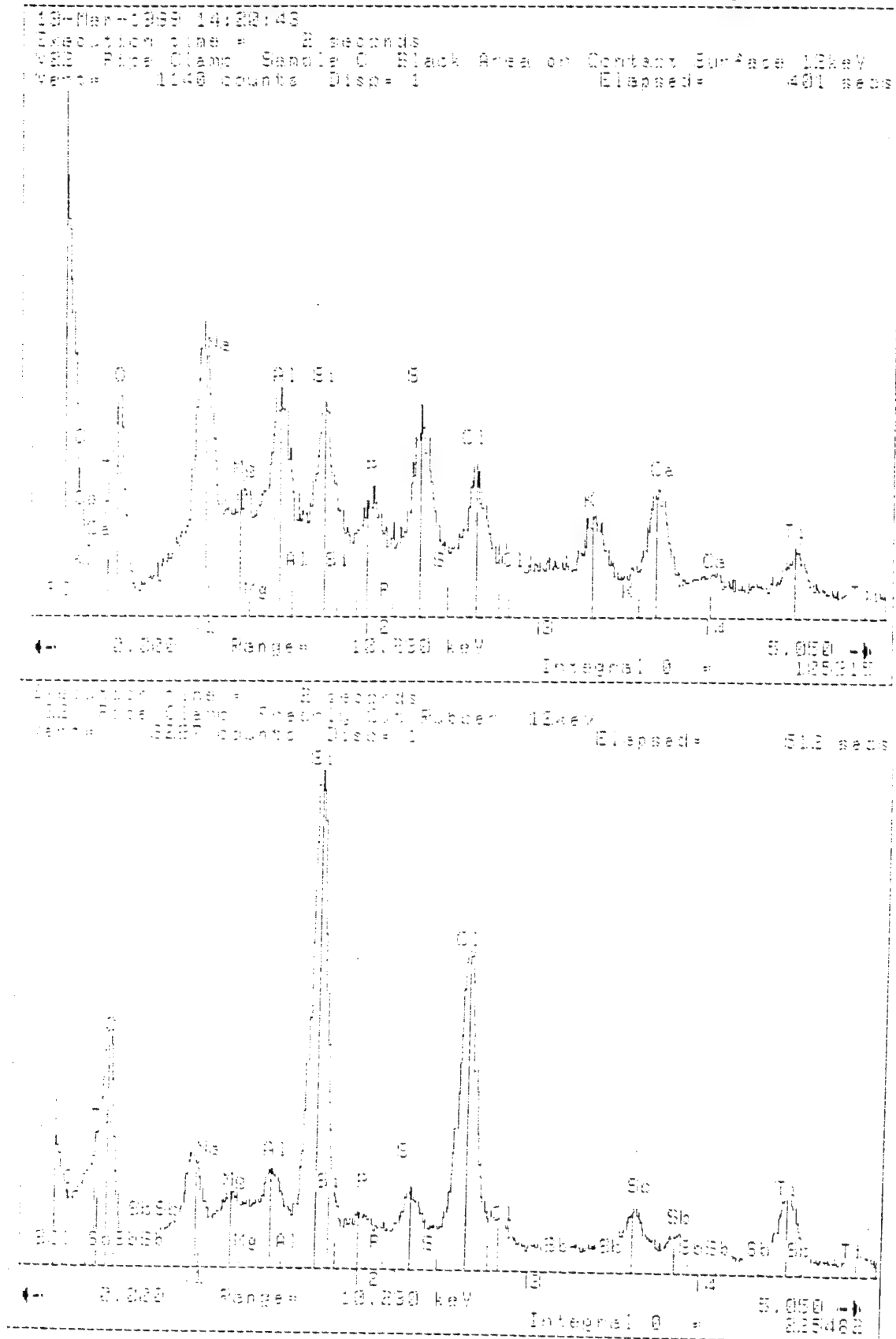
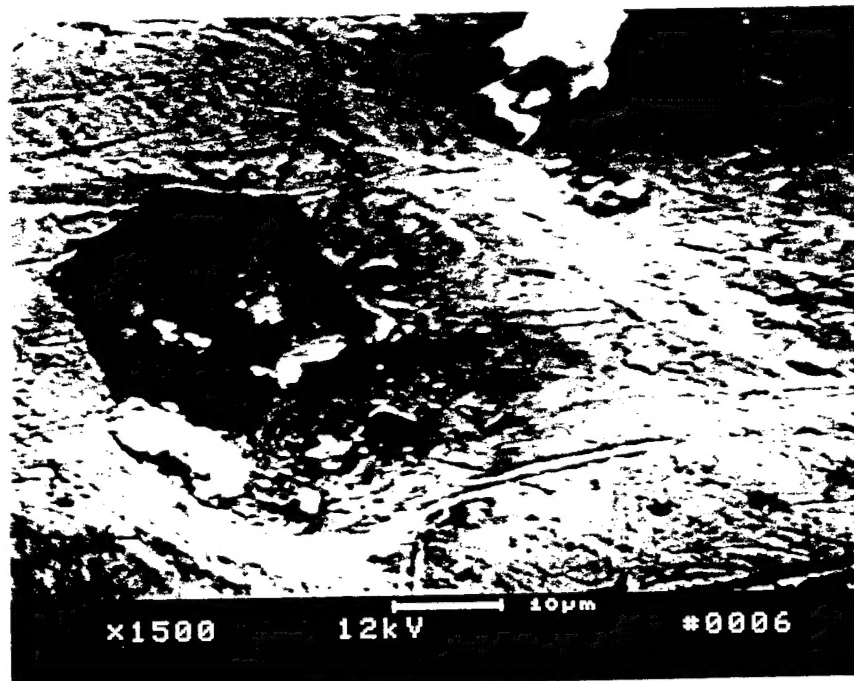
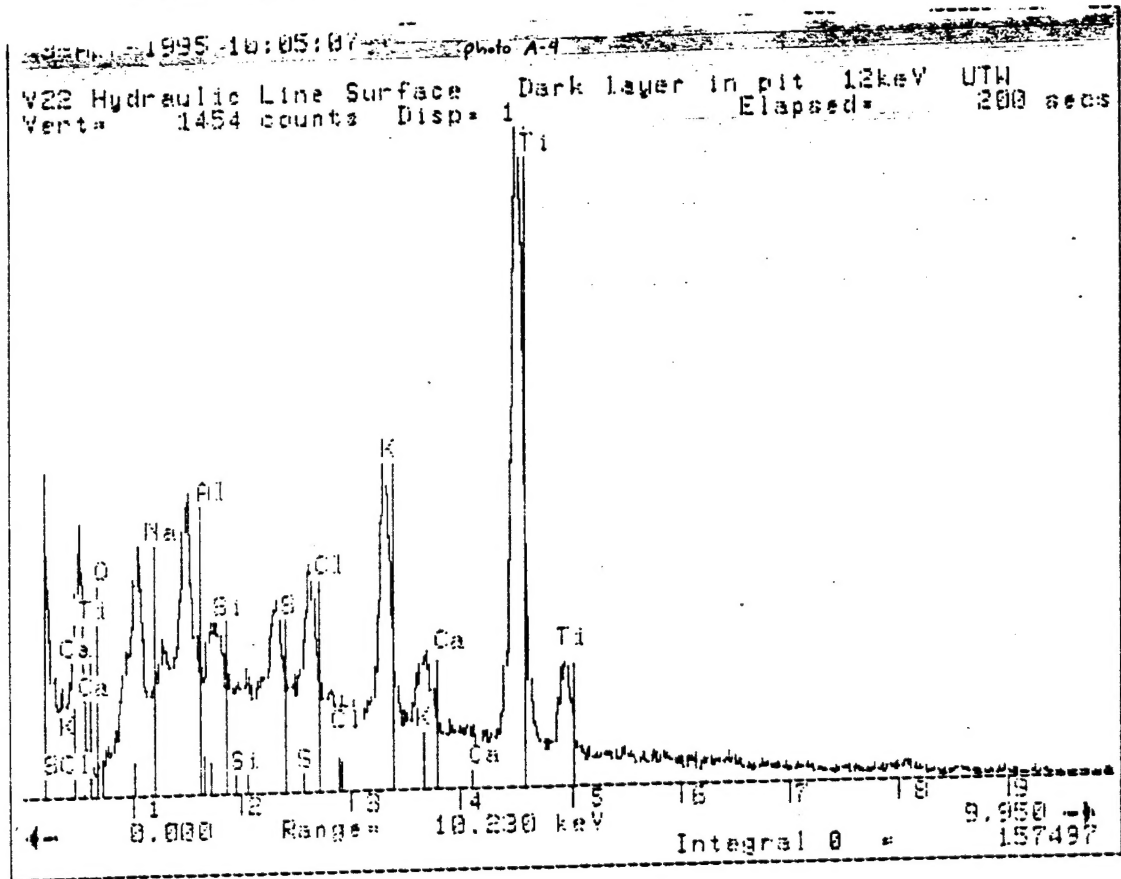


Figure 10: Elemental analysis (EDS), along with its corresponding SEM micrograph, of the darkened areas on the surface of the damaged V-22 Hydraulic Line.



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